HADRON PRODUCTION AND QCD IN DIS AT HERA

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La production de jets et de pions neutres de grands impulsion transversaux est étudiée avec les données de la diffusion profondement inélastique rassemblées avec les calorimètres de H1 et ZEUS de HERA. Les mesures sont effectuées à petits angles vis-à-vis du proton entrant, couvrant une domaine de Bjorken-x jusqu'à des valeurs de 10^{-3}. Pour les jets de grand $p_\perp$ et aussi pour les pions neutres de grand $p_\perp$ il y a une corrélation forte entre leur taux de production et les dynamiques sous-jacentes des partons. Les résultats sont présentés comme une fonction de Bjorken-x. Pour l'investigation de l'interaction de deux échelles fortes Q^2 et $E_\perp$, le taux de jets est montré comme une fonction de $E_\perp/Q^2$ dans un grand régime, couvrant aussi bien le DIS ($E_\perp < Q^2$) typique que le régime "du genre de la photoproduction" ($Q^2 > E_\perp$). Tous les mesures sont comparées aux prévisions Monte Carlo basées sur l'évolution DGLAP et sur BFKL, inspirées respectivement par des calculs QCD.

1 Introduction

HERA results on the structure function F_2 in the region of small Bjorken-x ($x_{Bjorken} \leq 10^{-3}$) have shown that the F_2 measurement, being inclusive, is too insensitive to discriminate between the competing parton evolution schemes DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) [1] and BFKL (Balitsky-Fadin-Kuraev-Lipatov) [2]. Therefore, it was suggested to have a closer look at the properties of the hadronic final state at low Bjorken-x being expected to be more sensitive to the parton evolutions [3].

Taking $\ln Q^2$ as the dominant term in the DGLAP evolution leads to a strong ordering of the transverse momenta of the emitted partons quite in contrast to the BFKL evolution where the $\ln Q^2$ terms are assumed to be negligible, and the $\ln(1/x)$ terms are taken to be dominant. The BFKL evolution allows the emitted partons to perform a random walk in the $k_\perp$-space ($k_\perp$ equals the transverse momentum of the parton) and requires a soft ordering in x_i, the fraction of the incident proton energy carried by the partons.

Another approach to emulate the random walk behaviour in $k_\perp$ implemented in the BFKL approach is also based on the DGLAP evolution but introduces in addition a resolved photon component in deep inelastic scattering [4]. It is assumed that for $k_\perp^2 > Q^2$ the parton starts to probe the virtual photon structure which then interacts via its hadronic substructure.

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The production of high transverse momentum jets and neutral pions is studied in deep-inelastic scattering data taken with the H1 and ZEUS calorimeters of HERA. The measurements are performed at small angles with respect to the incoming proton, covering a Bjorken-x range up to values of 10^{-3}. For both, the high $p_\perp$-jets and the high $p_\perp$-neutral pions there exists a strong correlation between their production rate and the underlying parton dynamics. Results are presented as a function of Bjorken-x. For the investigation of the interplay of the two hard scales Q^2 and $E_\perp$, the jet rate is shown as a function of $E_\perp/Q^2$ over a huge range covering the typical DIS ($E_\perp < Q^2$) as well as the "photoproduction-like" regime ($E_\perp > Q^2$). All measurements are compared with Monte Carlo predictions based on the DGLAP evolution and on BFKL inspired QCD calculations, respectively.

2 Introduction

HERA results on the structure function F_2 in the region of small Bjorken-x ($x_{Bjorken} \leq 10^{-3}$) have shown that the F_2 measurement, being inclusive, is too insensitive to discriminate between the competing parton evolution schemes DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) [1] and BFKL (Balitsky-Fadin-Kuraev-Lipatov) [2]. Therefore, it was suggested to have a closer look at the properties of the hadronic final state at low Bjorken-x being expected to be more sensitive to the parton evolutions [3].

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In this paper results from the H1 and ZEUS experiments on the jet and π° production in the direction of the proton remnant, the forward direction at HERA, are presented. Both measurements are well suitable to probe the QCD evolution dynamics.

3 Results

3.1 Forward jets

In the ZEUS measurement of the forward jet cross section [5] the following jet selection cuts have been applied: $\eta_{Jet} < 2.6$, $x_{Jet} = E_{Jet}/E_p < 0.036$, $0.5 < E^2_{\perp,Jet}/Q^2 < 2$, $E_{e'} > 10$ GeV, $y > 0.1$.

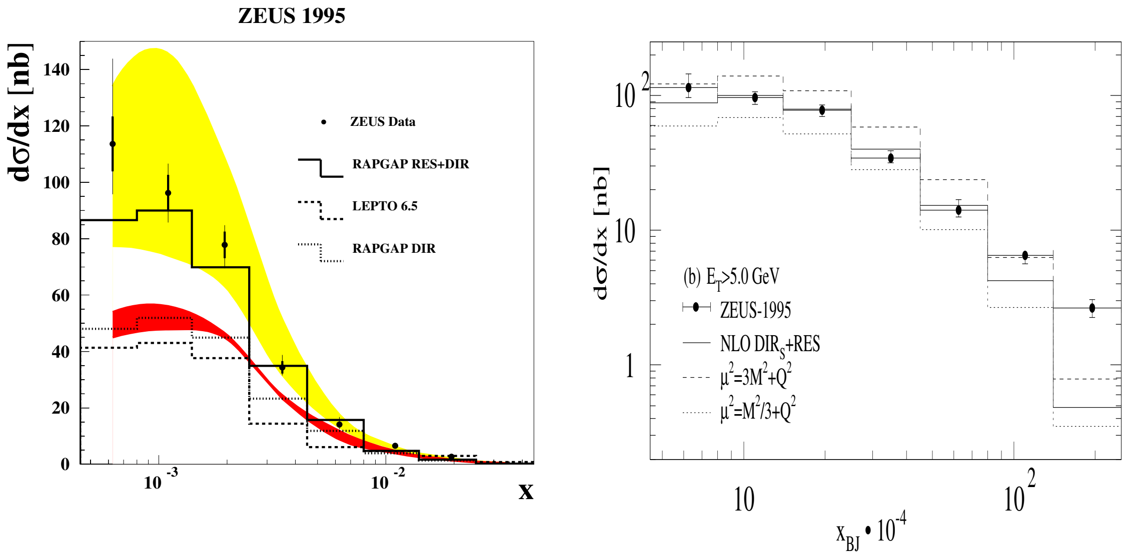

Figure 1: Left side: Forward jet cross section as a function of x. Statistical errors are shown as thick error bars and statistical and systematic errors added in quadrature as thin error bars. The two bands show the result of varying the factorization and renormalization scales in the RAPGAP calculations. Right side: The dotted and dashed lines show the result of varying the factorization and renormalization scales in the Next-to-Leading-Order calculations done by Kramer and Pötter[4].

Here η_{Jet}, E_{Jet}, $E_{\perp,Jet}$ denote the rapidity, energy and transverse energy of the jet, respectively, $E_{e'}$ the energy of the scattered electron, E_p the energy of the incoming proton. In the framework of the DGLAP evolution the cut on $E^2_{\perp,Jet}/Q^2$ and on x_{Jet} restricts the phase space for the parton emissions by exploiting their strong ordering in the $k_\perp$-space. Figure 1 (left side) shows the forward jet cross section as a function of Bjorken-x. The cross section rises steeply with decreasing values of x. The data are compared to the RAPGAP Monte Carlo model with direct and resolved contributions in LO QCD and to LEPTO, both models based on the DGLAP evolution. The prediction of LEPTO is clearly below the data, as is RAPGAP if only direct processes are included. Only RAPGAP with resolved contributions is able to describe the data but with large scale uncertainties marked by the shaded bands. (The renormalization and factorization scales have been varied between $(p^2_\perp/2 + Q^2)$ and $(4 \cdot p^2_\perp + Q^2)$).

Figure 1 (right side) shows the same ZEUS data as before but now compared with a Next-to-Leading Order QCD calculation including the virtual γ-structure done by Kramer and Pötter [4]. Good agreement of the predicted cross section with the data except for the largest x-bin is found.

ZEUS also measured the forward jet cross section [5] as a function of $E^2_{\perp,Jet}/Q^2$, a variable suitable to study the interplay and transition of the scales $E^2_{\perp,Jet}$ and Q^2 by scanning $E^2_{\perp,Jet}/Q^2$. Figure 2 shows the result: In the standard DIS regime $(E^2_{\perp,Jet} < Q^2)$ all MC predictions describe

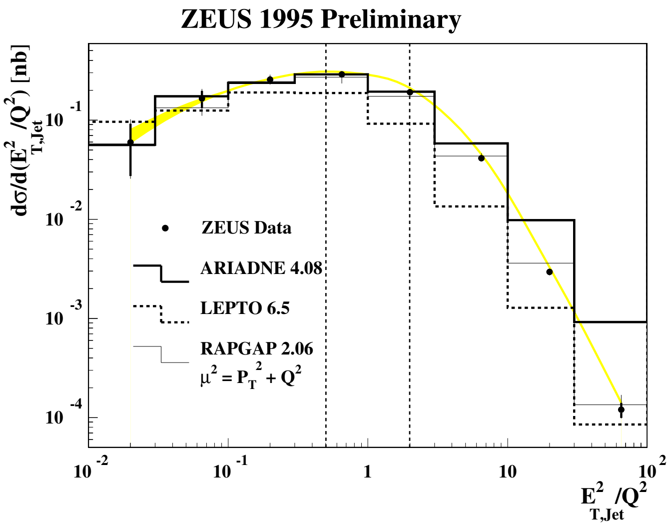

Figure 2: Hadron level forward cross sections as a function of $E^2_{\perp,Jet}/Q^2$. The inner error bars are the statistical errors. The outer ones are the statistical and systematic ones added in quadrature. The shaded band corresponds to the uncertainty from the energy scale of the calorimeter.

the data. In the transition region ($E^2_{\perp,Jet} \approx Q^2$) ARIADNE, based on the Colour Dipole Model, and RAPGAP (LO) with resolved components reproduce the data. One observes that only RAPGAP (LO) with resolved components is close to the data over the complete range scanned by the variable $E^2_{\perp,Jet}/Q^2$ including the region $E^2_{\perp,Jet} > Q^2$ where you have a situation quite similar as in photoproduction.

3.2 Forward π°s

In the H1 measurement of the π° cross section in the forward region [6] the π°-mesons are identified via their dominant decay channel $\pi^\circ \longrightarrow 2\gamma$. They are selected in the phase space region: $5^\circ < \theta_{\pi^\circ} < 25^\circ$, $p_\perp > 2.5$ GeV, $E_{\pi^\circ}/E_p > 0.098$ and $E'_e > 12$ GeV, where θ_{π°, $p_\perp$, E_{π° corresponds to the polar angle, transverse momentum and energy of the π°-mesons, respectively. At the high energies considered here, the two decay photons of a π°-meson cannot be resolved by the detector. They form a single cluster which has to be selected by measuring the shower shape of candidate clusters.

Figure 3 shows the π° cross section as a function of x and $p_\perp$ in different bins of Q^2. As in the case of the jet cross section presented above the DGLAP prediction of LEPTO is much below the data. A considerable improvement is achieved by introducing virtual γ processes as done in RAPGAP in LO QCD. In good agreement are the data with the BFKL calculation (modified LL) done by Kwiecinski, Martin, and Outhwaite [7].

4 Summary

The forward jet (ZEUS) and the forward π°-meson (H1) measurements supply a consistent picture of low x processes. LEPTO using QCD matrix elements in LO and parton cascades according to DGLAP evolution functions can neither describe the forward jet cross section nor the π° cross section. Including resolved virtual photon processes as done in the Monte Carlo model RAPGAP in LO QCD clearly improves the description of the data. The NLO calculations by Kramer and Pötter reproduce well the jet cross section, while the BFKL calculations by Kwiecinski, Martin, and Outhwaite are able to describe the x behaviour of forward π°-mesons.

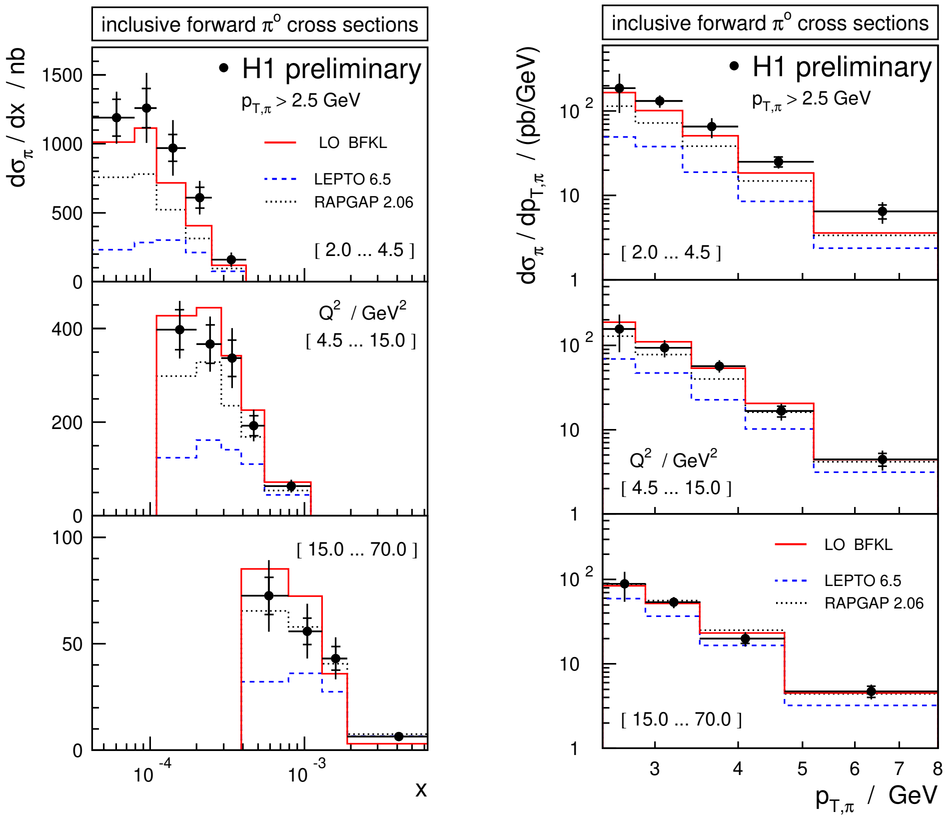

Figure 3: Inclusive π° cross section as a function of Bjorken-x and of $p_\perp$ in bins of Q^2.

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